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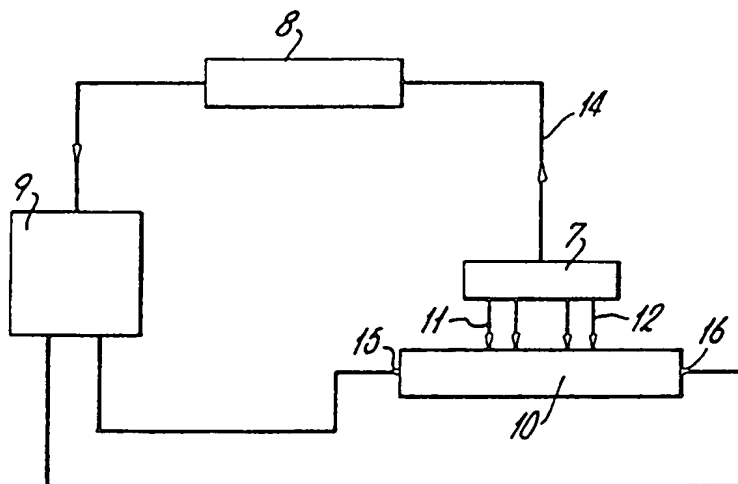**GB 1094303**

(58) Field of search
G1N
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(54) **Alternating current potential drop crack detection**

(57) An alternating current potential drop (ACPD) system for detecting and measuring cracks on the surfaces of electrically conducting materials (10) comprises a constant current AC generator 9 for applying current to material (10), a receiving unit 8 and a self-contained potential drop (PD) transducer unit 7 for attaching directly onto material surface 13. Two sets of detection probes 11, 12 measure the PD over a test area and an uncracked reference area respectively. The receiving unit 8 may be a microprossor controller.

The PD transducer 7 detects the PD on the material surface 13, converts the resulting analogue signal to a digital signal and transmits it to the microprocessor 8 where it is converted to a crack depth value. The signal may be transmitted to the microprocesor 7 via an optical fibre link 14.

The system is relatively immune to interferences and losses and is easily portable for use in the laboratory or in the fi ld.
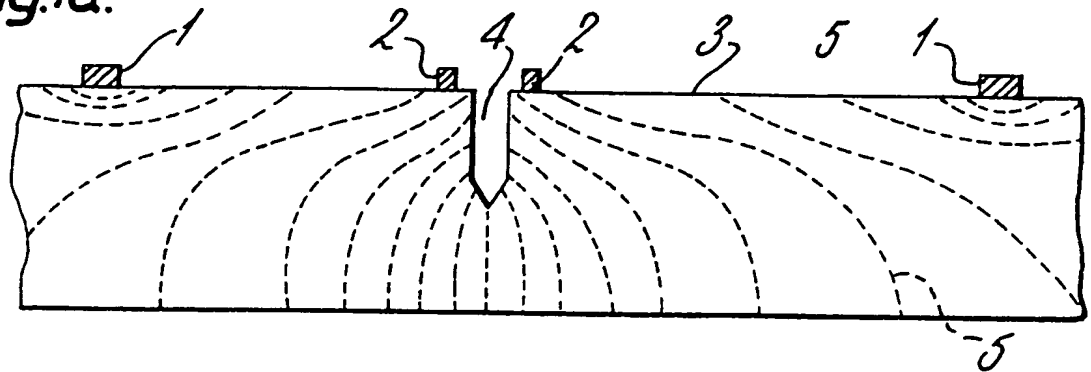
Fig.2.

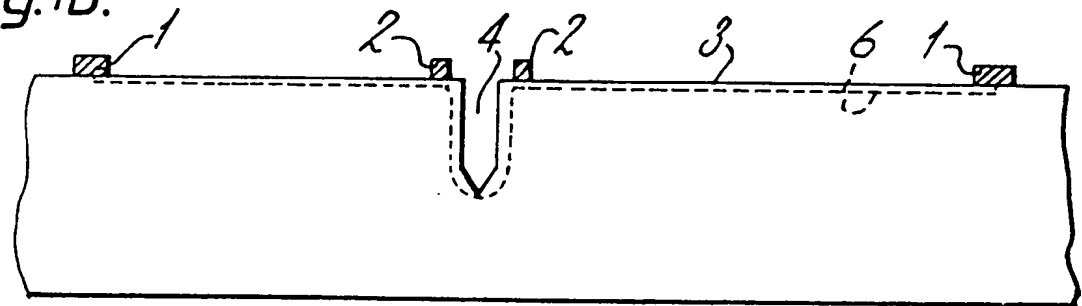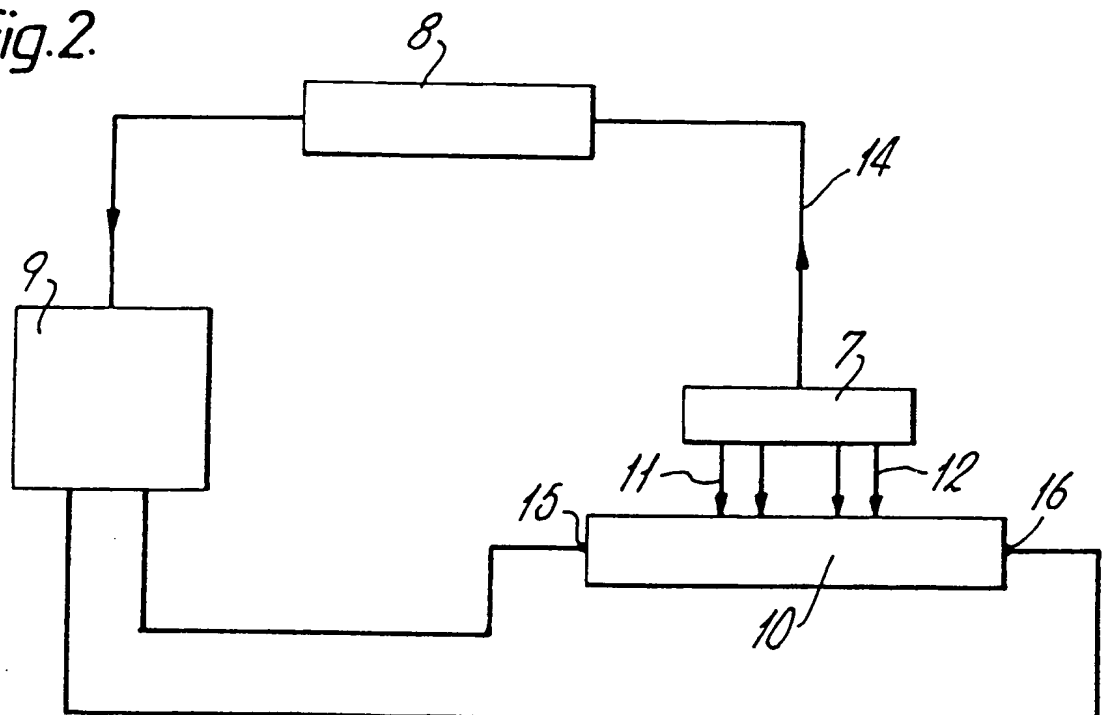

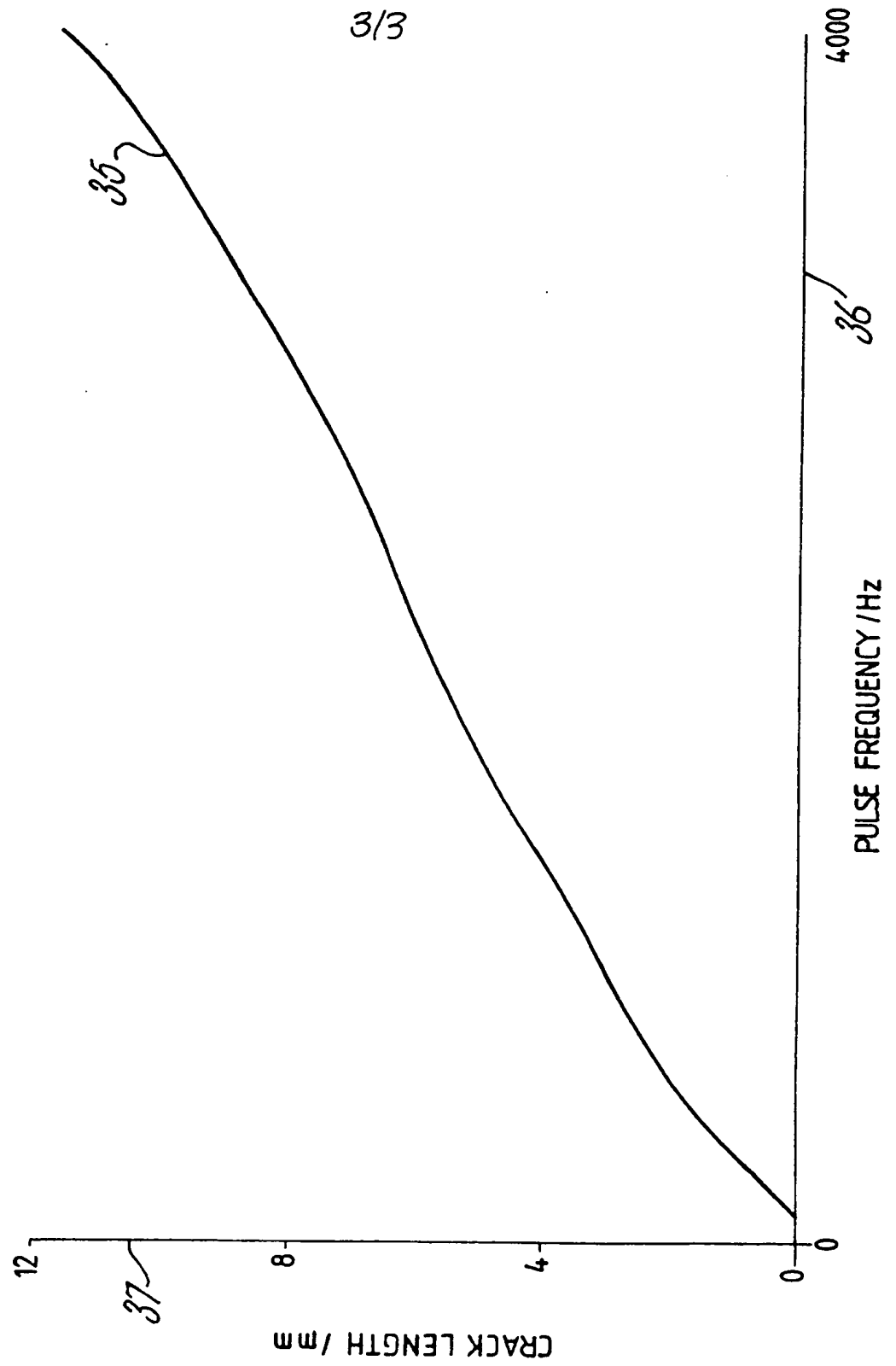GB 2 161 936 A

Fig.1a.

Fig.1b.

Fig.2.

2161936

Fig 3.

Fig.4.

SPECIFICATION

Improv ments in r relating to alternating curr nt p tential drop methods f r crack
5 **detection and measur ment**

The invention relates to methods for detecting and measuring cracks in material surfaces particularly, though not exclusively, for use ·
10 with metal or other electrically conducting material objects or structures.
Cracks due to fatigue or stress corrosion can occur on the surfaces of objects or structures under stress and the detection, monitoring
15 and sizing of such cracks is of great importance before the cracks lead to failure of the material.
One method used to detect such cracks involves passing an electrical current through
20 a material. This creates an electric field and the potential drop between any two points on the material surface can be measured. Any increase in the potential difference above the normal value will indicate the formation of a
25 crack and the increase can be related to the crack dimensions.
Early attempts to detect cracks using this method involved direct current field measurements. However, this technique is limited by
30 the high currents required on large structures and has little use apart from on small specimens in laboratory conditions.
To overcome this problem alternating current potential drop (ACPD) systems have been
35 developed.
In an alternating current system most of the current flows in a thin skin at the outer surface of the material ie there is a "skin effect". Thus, for a given voltage drop be-
40 tween two points on a surface, a much smaller AC field can be used compared with DC. The "skin depth" varies inversely with frequency.
Because of the skin effect, the measured
45 potential between two detection probes will be approximately proportional to the shortest peripheral distance between the two probes. Thus a crack in the surface will increase the measured potential drop compared to the
50 measured potential drop where there is no crack. Therefore the measurements of poten- tial drop can indicate whether a crack is present on the surface and, if the field can be measured accurately, the measurements can
55 be interpreted in terms of the crack size.
However, any system used for ACPD measurements must be capable of accurately measuring very small voltage differences and prior art ACPD systems have a major disadvantage
60 in that they are susceptible to interferences. Signals may be degraded due to losses or interference if th y are transmitted over any distance and, particularly in th crack initiation stage when any cracks and hence any
.65 changes in potential drop are very small, the

signals may be degraded to such an extent that no crack information can be obtained.
This problem may be r duced by transmitting the initial signals from the probes on the
70 material surface over the shortest distance possible before processing them.
The object of this invention is to provide an alternating current potential drop system for crack detention and measurement which is
75 relatively immune to losses or interference.
It is a further object of the invention to provide an ACPD system which is lightweight and portable, can be used on a wide variety of different materials, and gives good repeatabil-
80 ity and accuracy of results.
The invention provides an alternating current potential drop system for detecting and measuring cracks in the surface of a material wherein the system comprises a constant cur-
85 rent AC generator, a receiving unit and self-contained potential drop transducer unit for attaching directly onto a material surface, comprising a converter for changing the PD to a digitally encoded signal.
90 Advantageously the signal is frequency encoded, in that the output pulse frequency is dependant on the input potential drop.
Preferably the potential drop (PD) transducer unit houses signal detection and pro-
95 cessing circuits.
Preferably the PD transducer detects the potential drop on the material surface and converts the resulting analogue signal into a digital signal which can then be transmitted to
100 the receiving unit. This eliminates most of any possible interference.
Preferably all the circuits in the PD transducer are housed on a single printed circuit board.
105 Conveniently, contact with the material surface may be by spring probes, which ensure good electrical contact and repeatable results and also avoid the problems of spot-welding wires or the unpredictable contact of fixed
110 probes.
Preferably the probes are mounted directly on the printed circuit board and they may conveniently be made of gold-plated phosphor bronze, thus giving low contact resistance and
115 allowing high contact pressure. Conveniently they are able to extend into any notches present on the surfaces from which cracks may propagate.
Preferably there are two sets of detection
120 probes: one set to measure the potential drop between the test points and the other set to provide a reference potential drop over an uncracked area.
Preferably the first stage of the transducer
125 signal processing circuit is a differential output operational amplifier with dual inputs, one input being the PD across the test probes and the other input being the PD across the reference probes. Coveniently one of th inputs is
130 fitted with an offset null facility or trimmer

allowing the utput to be trimmed to z ro.

Preferably the signal from the first set of probes is fed into one pair of inputs in the operational amplifier and the signal from the
5 second set of probes is fed into the alternative inputs. The second signal may then be subtracted from the first. Conveniently the second signal can be attenuated by the trimmer to offset the signal from the first set of probes
10 when no crack is present, thus enabling the initial signal to be zeroed before further processing.

Preferably the PD transducer produces a digital signal suitable for direct computer pro-
15 cessing in the form of a series of pulses. Conveniently the pulses are transmitted from the PD transducer to the receiving unit in the form of pulses of light or infra-red radiation along an optical fibre, thereby preventing any
20 possibility of noise or other form of interference affecting the signal.

Preferably the PD transducer unit contains all the stages required to measure the difference between the potential drop at a test
25 point and at a reference point, amplify these signals, convert them to digital form and drive an infra-red or light radiation emitter for transmission of the pulses along the optical fibre to the receiving unit. A fibre optic link
30 for data transmission further reduces possible interference and has many other advantages including: freedom from electromagnetic interference; freedom from cross-talk in multifibre situations; security of signal transmissions;
35 elimination of sparking and fire hazards associated with long electrical wires; the transducer unit can be completely electrically isolated; ground loops can be avoided; the unit can be made low weight but still be strong;
40 and it is possible to have an increased bandwidth with lower losses at higher frequencies than would otherwise be possible.

An optical fibre system can be used to facilitate the transmission of a signal over
45 longer distances than are otherwise possible. It further increases the ACPD system's immunity to noise and also enables a single connection, requiring no reference, to be used between the PD transducer and the receiving
50 unit.

Preferably the signal from the transducer is received by an infra-red or light radiation optical detector as a series of pulses.

Advantageously the whole transducer unit is
55 screened to exclude any electromagnetic interference which might adversely affect the resulting signal.

Preferably the receiving unit comprises a microprocessor controller or microcomputer.
60 The microprocessor converts the r ceived signal into a value related to the depth of any crack which may be present.

Conveniently the microprocessor may also be used to control the current output and
65 frequency of the constant current generator.

This enables th ACPD system to be used to test a wide range of materials including nonmagnetic metals such as aluminium alloys and copper alloys. By increasing the frequency the
70 skin effect will be increased, producing a greater potential drop without having to increase the current. Also it is desirable that in use the frequency and current amplitude are optimised.
75 As the pulse frequency is proportional to the crack depth the microprocessor is advantageously able to count the pulses and thereby determine their frequency so that the value of the crack depth can be deduced.
80 Conveniently the crack depth is found from a calibration curve of known crack depths against pulse frequencies. The calibration is dependent on the type of material and therefore, for use with a variety of materials, cali-
85 bration curves should be provided for each material.

Alternatively the microprocessor can be used to calculate the crack depth from known formulae. For example, if the crack depth is x,
90 the voltage across an uncracked surface is V_u and the voltage across a cracked surface is V_c, then

$$95 \quad x = \frac{V_c - V_u}{2k}$$

where $(V_c - V_u)$ gives the pulse frequency and k
100 is a constant depending on the material.

Conveniently, if the system is being used under laboratory conditions to monitor the effects of loads on certain materials, the microprocessor can also be used to control the
105 load amplitude and frequency of a testing machine when applied to different specimens.

Conveniently the PD transducer may be battery operated, which is practicable because the power consumption may be made low.
110 Preferably the current inputs to the structure from the constant current generator are positioned so that the voltage distribution across the area of interest is as uniform as possible. In most situations the current inputs
115 can be a long way from the area of interest so that the field becomes uniform around that area. However, if a uniform field cannot be produced, the field in a small area can be examined and any changes from the normal in
120 that area can be used to indicate the presence of a surface crack.

Th current leads can be attached to the structure by a number of means such as sold ring, brazing, spot welding, spring con-
125 tacts, magnetic contacts, conducting adhesive or screw contacts. For laboratory testing of specimens the best and most reliable method was found to be screw c ntacts. However, in field situations the most convenient and relia-
130 ble method for any particular set of circum-

stances can be selected.

Because of the variation in sensitivity of the potential difference measurement probes with their position it is preferable, in the case of
5 measurements across a notch, for the probes to be inserted to a position near to the bottom of the notch for maximum sensitivity and repeatability.

Preferably the ACPD system of the inven-
10 tion is capable of being used in the laboratory to examine the behaviour of materials under loads or in the field to detect and measure cracks on a structure without any modifications to the system.

15 Preferably the PD transducer may be moved easily from one specimen or point on a structure to another. Conveniently it may held in position by a spring clip.

The use of a microprocessor enables a num-
20 ber of refinements to be made, particularly to the laboratory testing. The counter reading the pulses can be started or stopped at any time and so can be synchronised to read only during certain parts of a load cycle eg only
25 on-load to avoid closure effects or on- and off-load to examine the extent of closure effects.

Preferably the current generator unit may be included in the PD transducer unit to produce localised current pulses giving a lo-
30 calised field for measurement by the detection probes.

Preferably low loss optical fibres are used, with glass fibres being generally better than polymer fibres. However, low loss polymer
35 fibres may also be used.

In order that the invention may be more fully understood one embodiment thereof will now be described, by way of example only, with reference to the accompanying drawings
40 of which:

Figures 1(a) and (b) show the different current distributions near a notch in a material sample for the direct current and alternating current methods for crack detection respec-
45 tively.

Figure 2 is a block diagram of an alternating current potential drop system according to the invention.

Figure 3 is a schematic diagram of a
50 method of implementing a potential drop transducer of the ACPD system, showing the waveforms of a signal at various stages.

Figure 4 is a calibration curve for one material (a high strength steel).
55 Two conventional methods for crack determination and measurement are schematically shown in Fig. 1. Fig. 1a shows the current distribution for a direct current input. The current inputs 1 are at a distance from the
60 potential drop measurement probes 2 which are positioned on a surface 3 of a material. The probes 2 are sited on either side of a notch 4 from which a crack may propagate. Equipotential lines 5 indicate the field distribu-
65 tion.

Fig. 1b illustrates the "skin eff ct" present with an alternating current input. The current inputs 1 ar again positioned at a distance from the measurement probes 2 on either side
70 of the notch 4 but here the current follows a path 6 close to the surface 3 of the material.

The present invention makes use of the AC effect shown in Fig. 1b which has a particular advantage over the DC method of Fig. 1a in
75 that most of the current flows near to the material surface, enabling a lower current to be used to produce a given voltage drop.

Referring now to Fig. 2, a block diagram of the ACPD system is shown. The system com-
80 prises three main components: a potential drop (PD) transducer 7; a microprocessor controller 8; and a constant current generator 9.

The PD transducer 7 is attached to a specimen or structure 10 which is to be tested.
85 Two sets of measurement probes 11, 12 contact the surface 13 of the structure 10. The probes 11 measure the potential drop across a test area and the probes 12 measure the potential drop across an uncracked area to
90 give a reference voltage. The difference between the potential drop measured by the probes 11 and the probes 12 is then converted by the transducer 7 to a digital signal which is then transmitted along an optical
95 fibre 14 to the microprocessor 8 where it is converted into a value which can be equated to the depth of any crack which may be present between the two probes 11.

The transducer 7 contains all the stages
100 required:

a. to measure the potential drop at the test point and the reference point;

b. amplify the difference signals;

c. convert them to digital form; and
105 d. transmit a signal along the optic fibre 14 to the microprocessor 8.

By constructing the device, such that the signal processing circuitry is adjacent to the probes, circuit loops which are a source of
110 noise are reduced and the signal to noise of the device can be maximised.

The current generator 9 is a square wave constant current source which passes a current through the structure 10 via input and
115 output contacts 15, 16. The microprocessor 8 can be used to control the current output and frequency of the current generator 9 so that the current amplitude and frequency can be optimised for any particular circumstances.
120 Preferably a frequency of about 10kHz is used.

Referring to Fig. 3, the PD transducer 7 can be implemented as a six-stage signal conditioner. The signals from the two sets of
125 probes 11, 12 on the surface 13 are amplified by differential operational amplifiers 17, 18 and passed to the first stage of the signal conditioning circuits, a wide-band differential amplifier 19. The amplifier 19 has two-chan-
130 nel differential inputs 20, 21, a differential

output stage 22 and a full power bandwidth
of 50 MHZ. One of the inputs 20 is taken
from the defect or crack at probes 11 and the
other input 21 is taken fr m the reference
5 point at probes 12. The output 22 consists of
the difference between the two input signals
20, 21. The output' 22 is passed to the
second stage which is a gain stage consisting
of a single, low noise, low distortion differen-
10 tial operational amplifier 23, with a bandwith
of 150 KHz, which acts on signal S at the
output 22 and S̄ the antiphase component.
The signal from the differential output 22 of
the amplifier 19 is amplified to a level of the
15 same order as the supply voltage. The output
24 of the amplifier 23 is passed to the third
stage which is a peak detector 25 producing
an output 26 of a level proportional to the
amplitude of its input signal 24. The signal
20 26 is passed to the fourth stage, an integrator
27 with an output 28 having a rate of change
proportional to the level of the input 26. The
integrator 27 has a second input 29 for
resetting the output 28 to zero.
25 The signal 28 is passed to the fifth stage
30. When the input 28 of this stage 30
reaches a predetermined level the output 31
pulses. The output 31 is connected back to
the reset input 29 of the previous stage 27.
30 Stage 5 and Stage 4 combine to form an
analogue-to-digital converter.
The final stage is a unity gain current
booster 32 to provide pulses 33 for an infra-
red light emitting diode 34. The LED 34 is
35 narrow beam and high intensity and provides
an infra-red signal for transmission along the
optical fibre 14 (Fig. 2).
The waveforms of the signals at each out-
put stage 22, 24, 26, 28, 31, 33 are shown
40 graphically at 22a, 24a, 26a, 28a, 31a and
33a respectively.
Referring to Fig. 4, the calibration curve 35
for a high strength steel is shown. Changes in
pulse frequency 36 are shown against corre-
45 sponding changes in crack depths 37. It can
be seen that as the crack depth increases and
the potential drop increases, so the pulse
frequency increases. Calibration curves for
other materials are similar.
50 One or more calibration curves appropriate
to materials to be tested are stored for use by
the microprocessor. After detection and mea-
surement of a crack by the system the micro-
processor can be arranged to produce a visual
55 and/or audio indication of the condition of
the material sampled.
Although the system has been described
using a fibre optic connector between the
transducer unit and the microprocessor unit it
60 may be advantageous under certain circum-
stances to omit the infra-red emitt r and use
an electrical wire connection carrying electrical
pulses from the transducer unit to the micro-
processor.
65 A further cricuit modification (not shown)

has been found to improve the signal
strength. A transformer is connected between
the probes and the electrical circuitry to pro-
vide an impedance match and thereby in-
70 crease the signal for processing.
The ACPD system of the invention has
many advantages over prior art systems in
that: it is immune of interference; it has low
losses; it is lightweight and easily portable; it
75 can easily be moved from one test point to
another; it can be used on any electrically
conducting material; it gives good repeatabil-
ity and accuracy of results; it can be used in
the laboratory and in the field; it combines
80 low weight with high strength.
It also has several other advantages over
prior art systems such as:
a. The receiving unit is remote from the
transducer unit and non-specialised receiving
85 equipment can be used—standard data log-
gers or microcomputers can be used. This has
the additional advantage in that the output
information does not have to be specialised.
b. The receiving unit may be a program-
90 mable microcomputer so that changes for dif-
ferent materials or conditions can be pro-
grammed in so that ACPD system user can
indicate the conditions and the programme
will make any changes required for correct
95 measurement of crack depth.
c. The transducer is a small, compact unit
which is easily portable.
d. The frequency of the current generator
output can be varied so the frequencies can
100 be scanned and the changes in apparent crack
depth examined. This is particularly useful if
there may be branched or jagged cracks as in
these cases it is usually the depth of the crack
rather than the total crack length which is of
105 interest. If a shorter crack length is recorded
at low frequencies than at high ones the crack
is probably branched or jagged and low fre-
quency measurements may be used to predict
the crack depth rather than its overall length.
110 e. The possibility of using either a calibra-
tion method or a calculation method for find-
ing crack depths from the potential drop is
useful. The calibration method is accurate but
initially very time-consuming in that each dif-
115 ferent material has to be examined to produce
its calibration curve. The calculation method is
easier but not so accurate and requires extra
signal processing. It also requires some cali-
bration as there is a constant term which is
120 different for each material. A "material con-
stant" can be programmed in so that the
system can be changed from material to ma-
terial very easily. There is no difference in
operation between either method for the end-
125 user so the method used may be decided on
cost and accuracy requirements.

CLAIMS
1. An alternating current potential drop
130 (ACPD) system for detecting and measuring

cracks in the surface of a material comprising:
   a. a constant current AC generator;
   b. a receiving unit; and
   c. a self contained potential drop (PD)
5 transducer unit for attaching directly onto a
material surface comprising a convertor for
changing the PD to a digitially encoded signal
for transmission to the receiving unit.
   2. An ACPD system according to Claim 1
10 wherein the signal is frequency encoded in
that the output pulse frequency is dependent
on the input potential drop.
   3. An ACPD system according to Claim 1
or Claim 2 wherein signal detection and pro-
15 cessing circuits in the PD transducer are
housed on a single printed circuit board.
   4. An ACPD system according to any one
preceding claim wherein there are provided on
the transducer unit two sets of detection
20 probes: one set to measure the potential drop
between test points and the other set to
provide a reference potential drop over an
uncracked area.
   5. An ACPD system according to Claim 4
25 wherein contact with the material surface is
by spring probes.
   6. An ACPD system according to Claim 4
or 5 wherein the first stage of the transducer
signal processing circuit is a differential input
30 operational amplifier with one input being the
potential drop across the test probes and the
other input being the potential drop across the
reference probes.
   7. An ACPD system according to claim 6
35 wherein transformer impedance matching is
used between the probes and the signal pro-
cessing circuitry.
   8. An ACPD system according to Claim 6
or 7 wherein one of the inputs is fitted with
40 an offset null facility or trimmer allowing the
output to be trimmed to zero.
   9. An ACPD system according to Claim 8
wherein the pulses are transmitted from the
PD transducer to the receiving unit in the
45 form of pulses of light or infra-red radiation
along an optical fibre.
   10. An ACPD system according to any
one preceding claim wherein the transducer
unit is screened to exclude electromagnetic
50 interference.
   11. An ACPD system according to any
one preceding claim wherein the receiving
unit comprises a microprocessor controller.
   12. An ACPD system according to Claim
55 11 wherein the microprocessor converts the
received signal into a signal related to the
depth of any crack which may be present.
   13. An ACPD system according to Claim
11 or 12 wherein the microprocessor is used
60 to control the output current amplitude and
frequency of the constant current generator.
   14. An ACPD system as claimed in any
one preceding claim wherein the frequency of
the constant current generator is selected to
65 be substantially 10kHz.

   15. An ACPD system as hereinbefore de-
scribed with reference to Figs. 2 and 3 of the
drawings.